

ABSTRACT

The development of next-generation hybrid energy storage systems heavily relies on the search for sophisticated electrode materials with high electrochemical activity and structural durability. This study used sodium 5-sulfoisophthalate (SSIPA) as the primary ligand and 1,3,5-benzene tricarboxylic acid (BTCA) as a co-ligand to successfully synthesize a chromium-based metal-organic framework (Cr-1,3,5-BTCA-MOF) via a sonochemical approach. Through distinctive variations in carboxylate stretching vibrations and the appearance of a distinct metal-oxygen band at 531 cm^{-1} , Fourier transform infrared spectroscopy (FTIR) validated framework construction and proved Cr-O coordination. By using UV-Visible absorption spectroscopy to analyze optical characteristics, the MOF showed a λ_{max} at 249 nm with an absorbance of 2.15, which corresponds to a $\pi \rightarrow \pi^*$ transition. A noticeable red shift was seen in comparison to the free co-ligand ($\lambda_{\text{max}} = 212\text{ nm}$), suggesting improved conjugation and effective metal-ligand coordination. A direct band gap of 4.97 eV was also discovered via Tauc plot analysis, underscoring the material's potential for optoelectronic uses because of its effective direct electronic transitions. Electrochemical impedance spectroscopy (EIS), galvanostatic charge-discharge (GCD), and cyclic voltammetry (CV) were used to assess electrochemical performance. The Cr-MOF demonstrated remarkable pseudocapacitive behavior in a three-electrode system, delivering a specific capacitance of 245.11 F g^{-1} at 1.11 A g^{-1} and a specific capacity of 122.55 C g^{-1} . A hybrid device (Cr-MOF//AC) achieved a specific capacity of 21.35 C g^{-1} , capacitance of 14.23 F g^{-1} , energy density of 4.44 Wh kg^{-1} , and power density of 715.55 W kg^{-1} while operating over a broad potential window of 0–1.5 V. Capacitive contributions increased from 30% at 10 mV s^{-1} to 49% at 50 mV s^{-1} , according to Dunn's research. The hybrid device's b-value improved from 0.57 (MOF alone) to 0.72, with an R_2 value of 0.99, indicating outstanding reversibility. All of these results show that the sonochemically produced Cr-1,3,5-BTCA-MOF is a promising option for next-generation hybrid supercapacitor applications due to its synergistic optical and electrochemical features.